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Test and Reconstruction of Air Conditioning System in a Hotel Lobby

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Abstract: Two air conditioning systems are equipped in a hotel lobby. It is found from the field test that the actual air rate is 40% and 16% of the nominal value, respectively, of the two systems, which is far lower than the design requirement. The air rate of the outlets varies greatly, and the coefficient of uniformity is 129.1% and 111.6% respectively of the two systems. Air distribution in the lobby is bad and thermal comfort is poor. Moreover, sharp reduction of return air makes portions of fresh air increase, which will lead to high energy consumption. Reconstruction is carried out to improve the thermal environment with the assistance of the CFD method. First, the original system is simulated by CFD method to verify the CFD method and propose modification suggestions. Then air conditioning load and air rate of the lobby is recalculated and duct redesigned. Simulation results show that the air distribution and thermal comfort of the improved scheme can meet the design requirement. The reconstructed system has been running for about two years and has shown good performance.

Key words: field test; reconstruction; hotel lobby; CFD (Computational Fluid Dynamics) method; energy efficiency

1. INTRODUCTION

The building which height exceeds 5m or volume larger than 10,000m^3 is generally called high space building[1]. Air conditioning design for high building should pay more attention in air distribution, which has the critical effect on thermal comfort and energy efficiency.

For some existed high space buildings which air distribution is not designed properly, reconstruction is necessary to improve the level of thermal comfort and reduce the energy consume. The new developed CFD method is proved to be an effective tool in this procedure because it can provide visual results, speed up the process and cut down the cost evidently. Here, a case study of reconstruction is carried out take the advantages of the CFD method.

2. OVERVIEW OF THE PROJECT

The outline of the hotel lobby is shown in Fig.1. and Fig.2. Fig.2 only displays the east part for clear view because the lobby is symmetrical.

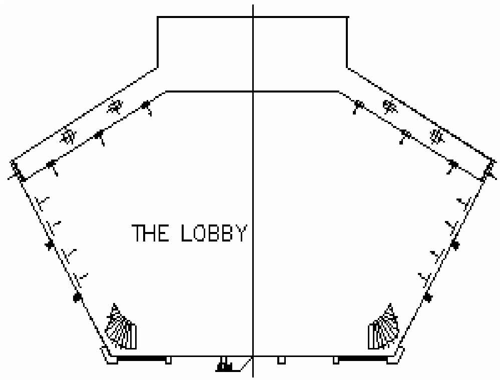

Fig.1 Outline of the lobby (the original design)

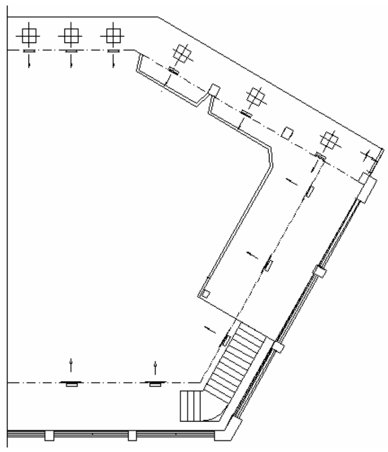

Fig.2 Outline of the mezzanine (east side of the original design)

The lobby has the height of 6m, width of 36m and depth of 18m. There are two mezzanines for coffee bar and tearoom symmetrically at the east and west side. The east and west building envelope is made up of single-glassed aluminum alloy outer windows with 600mm high windowsill. The south building envelope includes French windows and entryway. The roof is made up with light heat preservation material[2].

The original air conditioning system uses the primary return air scheme. There are two independent systems serve east and west side of the lobby respectively. Each system has a floor standing type air conditioner with the rating refrigerating effect of 80600kW, air rate of 15,000m^3/h and air pressure of 360Pa.

Two kinds of air supply openings are used, diffuser is used for the coffee bar and tearoom at mezzanines and double deflection register is used for side air supply at the height of 3m and 5.6m. The return air inlets locate at the side wall near the air conditioner plants.

The effect of the air conditioning system is not good from the beginning according to the operating reports. The thermal environment of the lobby still can’t get to a satisfactory level even after several partial modifications in recent years.

3. FIELD TEST

To evaluate the performance of the air conditioning system, field test is carried out for air conditioning systems and thermal environment of the lobby. Air rate of supply and return, velocity of the outlets, velocity and temperature in the lobby etc. are tested.

3.1 Air Rate of the Air Conditioners

Table. 1 shows the tested air rate data of the air conditioners. It can be seen that the actual value of east unit is 6,000.8m^3/h, which is 40.0% of the rated value 15,000m3/h, 2,514.7m^3/h for the west unit, which is only 16.8% of the rated value. The rate of air supply can’t reach the requirement.

During the test, it’s found that the average velocity of the east unit’s outlet is 4.67m/s. It can be calculated that if the air rate reach the rating 15000m^3/h, the average velocity in the wind duct will be about 11.66m/s. High air speed will increase the duct resistance and then consume more energy, increase the air leakage and cause more noise.

Tab.1 Air rate of the two units

	Fan number	Average velocity (m/s)	Air rate (m^3/h)	Total air rate (m^3/h)
East unit	1	3.45	1478.0	6000.8
	2	4.78	2048.8	
	3	5.78	2474.0	
West unit	1	1.61	689.7	2514.7
	2	2.11	902.9	
	3	2.15	922.1	

3.2 Air Rate of the Outlets

There are 27 outlets at the two sides of the lobby symmetrically. Their position and number is shown in Fig.3. Duct of each air supply system is divided into 4 branches named A, B, C and D.

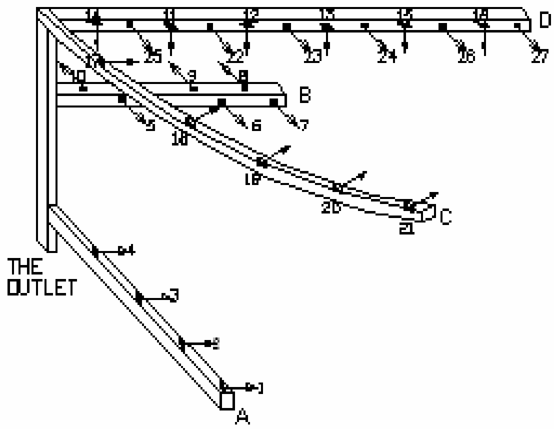

Fig.3 Air supply system of the western side (the original design)

The tested air rate values of outlets are plotted in Fig.4. Imbalance of the air rate lies between the outlets. Coefficient of uniformity is 129.1% and 111.6% for west and east system respectively.

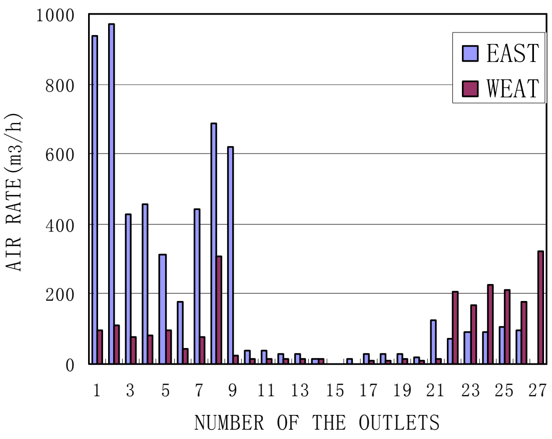

Fig.4 All the results of the outlets' air volume

From the test results, we can also conclude that:

First, air rate of the 4 branch is out of balance. If each outlet has the same air rate, the ratio of the western 4 branch should be 1:1.25:1.25:3, but the actual value is 1:0.8:0.04:0.3, which means air rate of branch C and D is badly insufficient. Since air rate of the unit (6,000.8m^3/h) and total air rate of all the outlets （5,877.8m^3/h） is close, the air leakage factor may be ignored. Then it may be caused by the following reasons, one is branch C and D are longer than A and B, the original design didn't considered the hydraulic misadjustment, another is the air-valves' opening of branch C and D are not enough, or the duct is blocked up.

Secondary, air rate of the outlets at the same branch is out of balance. In branch A for example, air rate of outlets numbered 3 and 4 at the far end of the branch is only half of that of the 1 and 2 outlet at the near end.

Finally, velocity distribution of some outlets is nonuniform. It may be caused by the block up of the filters or the distribution of the static pressure in the duct.

3.3 Rate of the Return Air

The rate of return air of west system is 317.4m^3/h, then the rate of fresh air is 2,197.3m^3/h when the total supplied air rate of unit is 2,514.7m^3/h, this means the proportion of the fresh air is 87.4% and will cause energy waste.

For east system, the rate of fresh air is 3,047.7m^3/h, which is 50.8% of the total supplied air rate.

Although the rate of fresh air of the two systems is close, the proportions of fresh air have large difference. That means the air return situation of west system is worse.

Data of the test points in the lobby reveal the same problems. Jet flow of the outlet decays quickly. Velocity in the resident region is small, sometime can hardly be tested or sensed. It's hot in summer and cold in winter, air is not fresh, and people feel uncomfortable in the lobby while the power consumption is still high.

4. THE RECONSTRUCT DESIGN

The system is redesigned according to the test results and the primary CFD analysis (see next part for details). The duct is resized, openings are reused as possible.

The new system is also symmetrical, but divided into two zones based on the load and geometry. The inner zone support the load inside the lobby, includes double deflection registers at the height of 3m and nozzle outlets at 5.6m. The outer zone includes slot outlets near windows close to the mezzanine and twist outlets near the door. Nozzle outlet and twist outlet is used for far jet flow range, one for side supply, another for down supply.

Fig.5 and Fig.6 show the detailed duct and outlets arrangement of the redesigned scheme.

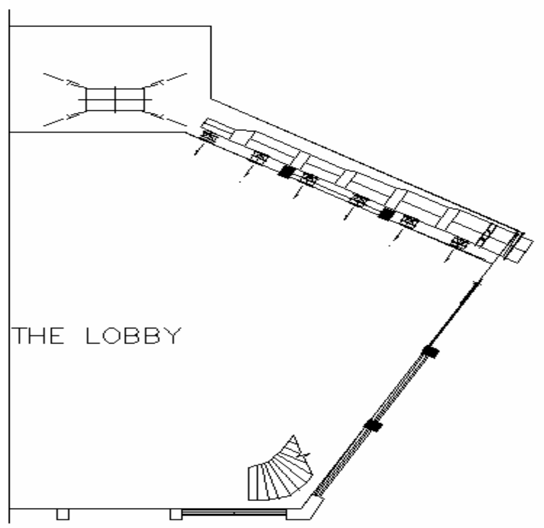

Fig.5 Outline of the lobby (redesigned)

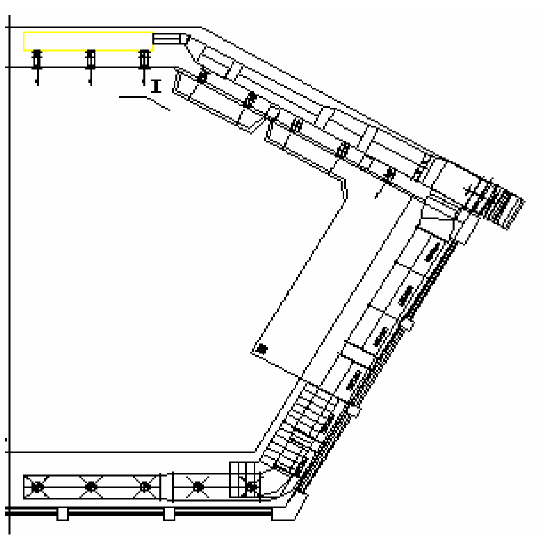

Fig. 6 Outline of the mezzanine (redesigned)

Different kind outlets are selected for different circumstance.

In the outer zone, peripheral outlets such as slot and twist outlets can effectively prevent the heat transfer between outdoor and indoor through the outer building envelope, they can also reduce the heat loss by infiltration, make the indoor thermal environment less affected by outdoor conditions.

The area of inner zone near the bar counter is the chief resident region, side supply double deflection registers set in the ceiling above the bar are used to meet the air conditioning requirement. Area further than 7~8m is support by the nozzle outlets which can supply the air to the central of the lobby.

Return air inlets are set at the inner side of the lobby under the nozzle outlets, which can make most human activity region in the return flow zone.

5. THE CFD ANALYSIS

CFD simulation is carried out to evaluate the air distribution and thermal comfort of the original and the redesigned scheme.

The standard k-ε model is adopted as the turbulence model, constants all set as default values[3][4]. Since the lobby and the air conditioning system is symmetrical, only east half is simulated to save the amount of calculation and the time.

Boundary conditions of the original scheme simulation come from the test, and use the data of the test points in the lobby for verification of the CFD method and the model.

Results of the CFD simulation fit well with the test data, Velocity is low, temperature can't reach the design requirement. Fig.7 shows the horizontal velocity contour at the z=1.8m section plane, here y point to north and z point to the upwards direction. Situation of other planes are similar.

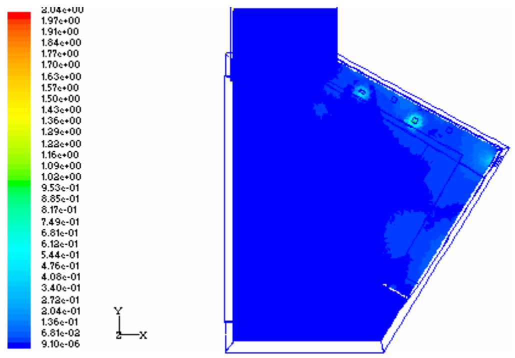

Fig.7 Horizontal velocity contour of original scheme (z=1.8m)

CFD simulation of the redesigned scheme uses the design values as the boundary conditions assumed that the reconstructed system can reach the requirement of the design after regulation.

Results of the horizontal air distribution are shown in Fig.8 to Fig.10. It can be seen that the velocity is higher than the original scheme.

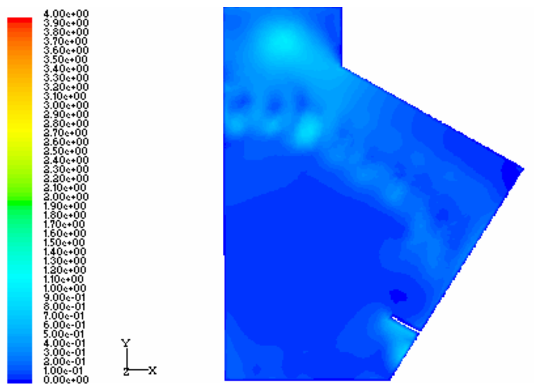

Fig.8 Horizontal velocity contour (z=1.8m)

At the z=1.8m plane, velocity near the return air inlets (upside of the figure) is higher, about 0.5~0.7 m/s. It's about 0.3~0.4 m/s near the stairs to the mezzanine due to the obstruction of the stair. Region under the mezzanine has the velocity no more than 0.3m/s, where is usually used as resting place, coffee bar or tearoom. Velocity of the air flow is lower at the middle of the lobby. All data are in the comfortable range.

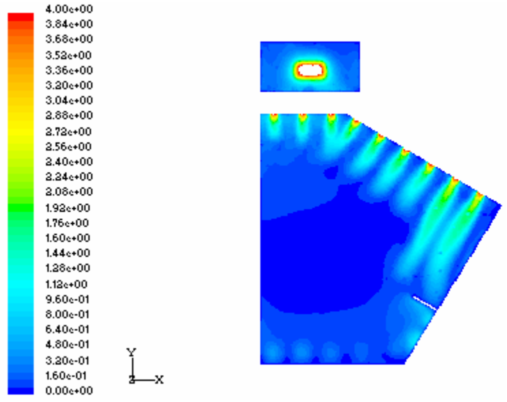

Fig.9 Horizontal velocity contour (z=2.8m)

The plane at z=2.8m cut through the side supply outlets. Decay of the jet flow can be seen. Flow out of the right two outlets have longer throw because they are located under the mezzanine floor which induced wall attachment jet.

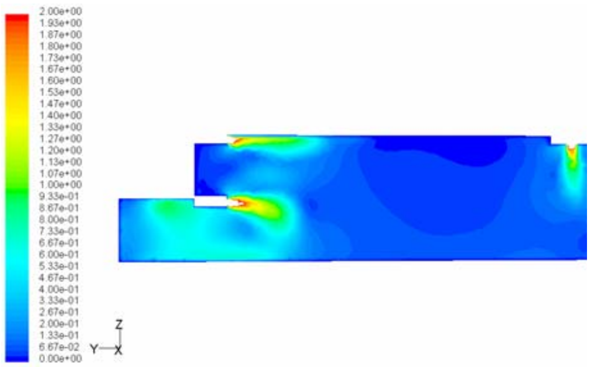

Fig.10 Vertical velocity contour (x=5m)

The plane in Fig.10 offsets 5m to east from the symmetry plane of the lobby. Property of jet flow out of three kinds of outlet can be observed.

In general, the redesigned scheme can provide an environment meet the requirement of thermal comfort, its mean PMV value is -0.12, standard deviation of PMV distribution in resident region is 0.31.

The air conditioning system is reconstructed according to the redesigned scheme. Additional test has been carried out to evaluate the system, the data fit well with the simulation. Further analysis is omitted due to the limit of space in this paper. Now the new system has been running for about two years and shown good performance.

6. CONCLUSION

(1) Air conditioning system of a hotel lobby is tested, and then reconstructed with the assistance of CFD method. By simulate the air distribution of the lobby CFD method can provide visual and detailed information quickly, which is useful in scheme evaluation, comparison and improvement.

(2) Hydraulic calculation should not be omitted during air conditioning system design procedure, or imbalance of air rate may occur, and then worsen the performance of the system and waste more energy.

(3) Air supply mode and arrangement of the outlets is important to the air distribution. Properly design may lead to a thermal comfortable indoor environment.

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